9.0 LAKE TAHOE BASIN-WIDE GROUNDWATER NUTRIENT LOADING

9.1 Basin-Wide Data Gaps

Systematic groundwater investigations should be conducted throughout the basin, especially in the more populated parts and where they coincide with sedimentary fill basins. Investigations should be designed to define vertical and horizontal variations in flow, mixing among various zones, and interaction with surface water and the lake shore zone. These factors are pertinent for better understanding available resources and for defining management strategies for protecting those resources. Geochemical analyses should be performed to adequately define variations among shallow, intermediate and deep aquifer systems and to determine groundwater evolution trends as water travels from the mountain slopes to the lake. Geologic and geophysical evaluations should be conducted to more accurately define aquifer parameters, water basin boundaries and the importance of confining horizons. Much controversy exists about the extent and continuity of fine-grained horizons in South Lake Tahoe. Such units should be adequately defined there and in other parts of the basin.

Survey data for the wells and stream gage stations, for the most part, has not been collected. This is a minor activity that could improve the loading calculations by providing better data for more accurate gradients. When possible, groundwater level data should be obtained for all wells during sample collection. This too would provide a more complete data set to determine accurate gradients in the basin.

A consistent set of nutrients monitored would provide a more complete dataset for evaluation. Specifically, additional organic nitrogen and total phosphorus testing would provide a more complete dataset.

9.2 Error Analysis

The accuracy of the groundwater discharge and nutrient loading estimates are a function of the input parameter data quality. The data set is limited for the basin, thereby reducing the level of accuracy in the estimates. Unfortunately, the lack of data also hinders the assessment of accuracy. The discussion of errors is qualitative.

Groundwater level measurements are accurate from 0.03 m to 6 m (0.1 foot to 20 feet). This broad range of accuracy is due to only a handful of wells with survey data. The vertical coordinates of the remainder of wells has been estimated by topographic maps, inducing an error of one half a contour interval. In addition, the horizontal accuracy of the wells is poor because of the lack of survey data. These factors combined limit the accuracy of the hydraulic gradients estimated.

Hydraulic conductivity estimates were based primarily on drillers' well logs. The literature was also searched for better descriptions of the geology. The poor quality of drillers' reports and lack of sufficient geological investigations produces errors associated with these estimates. This is probably the largest source of error in most parts of the basin. The aquifer area also suffers from the lack of geological investigations. The depth to bedrock and potential confining layers are also inferred from drillers' well logs. The well logs tend to be inconsistent, introducing error into the estimates of geological parameters. The lack of data from fracture flow is also a problem. There is a potential to have significant flows from the fractured bedrock that is not evaluated.

The accuracy of the chemical analysis is likely the most accurate. The groundwater samples are representative of the aquifer chemistry to the extent collection and analytical methods are valid. The extrapolation of the groundwater chemistry to other parts of the basin based on land use, average or downgradient estimates can induce error. Similar land uses may not be directly comparable throughout the basin. A good example of this is residential land use. There are neighborhoods in the basin with manicured lawns and other with natural vegetation. These two types of neighborhoods may have drastically different groundwater loading associated with them. This type of information was not available, and therefore was not considered in the estimated land use averages. In addition, many of the wells are screened in the deep aquifer. The analytical results may not accurately reflect the upper aquifer which likely contains the highest levels of nutrients.

9.3 Seasonal Variation of Nutrient Loading

A limited evaluation was conducted to determine if the groundwater loading is affected seasonally. Many wells have a limited data set which does not provide information seasonally. However, the evaluation was conducted using this limited data set. The only factor with potential seasonal variation using the Darcy's Law approach is hydraulic gradient. The estimated hydraulic gradient for two regions was evaluated. The average gradient did not vary by more than 0.01 seasonally. This indicates that there is little variation in groundwater discharge seasonally. In addition, nutrient concentrations were evaluated to determine if there was a difference between concentrations seasonally. The average seasonal concentration difference of all species of nitrogen and phosphorus evaluated as part of this study was less than 2 times. Considering the uncertainty associated with the groundwater nutrient loading estimates, the seasonal variation does not appear to be significant. The best data available is that presented in the groundwater flow model for South Lake Tahoe. It would be reasonable to assume a similar change in flow in the other areas of the lake as is seen in South Lake Tahoe. This model showed that changes are more likely on a yearly basis rather than seasonally.

9.4 Shallow vs. Deep Nutrient Concentrations

An evaluation of the concentrations in deep versus shallow wells was conducted for wells in the basin. Deep wells are those with open intervals greater than 1.5 meters (50 feet) below ground surface. Well construction information is not available for all wells. If a screen interval or open interval was unavailable, the wells were not included in the evaluation. The average concentration of nutrient species of concern were determined and shown in Table 9-1. This evaluation showed that nitrogen concentrations were 2 – 5 times higher in the shallow groundwater and the difference was statistically significant ($p<0.05$). The difference in nitrate concentrations from deep to shallow aquifer was the most apparent with a p-value <0.001. It is expected that anthropogenic sources would have a more profound effect on the shallow aquifer. This is shown by the lower percentage of nitrate coming from ambient sources. Phosphorus, on the other hand, showed no statistical difference in the shallow versus deep aquifer ($p>0.05$).

Table 9-1. Nutrient Concentrations in Shallow vs. Deep Wells

Constituent	Number of Samples	Average Concentration	Standard Deviation	Minimum	Maximum
Shallow Wells					
Ammonia + Organic	86	0.49 (0.05)	1.7	0.01	15
Nitrate	127	0.75 (0.46)	0.87	0.002	3.6
Total Nitrogen		1.2 (0.51)			
Orthophosphorus	91	0.024 (0.016)	0.030	0.002	0.21
Total Phosphorus	122	0.038 (0.03)	0.034	0.01	0.27
Deep Wells					
Ammonia + Organic	163	0.11 (0.04)	0.22	0.001	2.1
Nitrate	661	0.330 (0.15)	0.38	0.002	2.5
Total Nitrogen		0.44 (0.19)			
Orthophosphorus	173	0.10 (0.039)	0.66	0.005	8.8
Total Phosphorus	635	0.048 (0.03)	0.056	0.009	0.78

Notes:
1. Deep wells are those with open intervals greater than 1.5 m (50 ft) bgs.
2. Only wells with construction information were used in this evaluation.
3. Nitrate concentrations include nitrite.
4. Total Nitrogen is calculated as ammonia + organic + nitrate.
5. (#) in the average concentration row are median values.

9.5 Overall Nutrient Loading to Lake Tahoe

Regional groundwater discharge and loading estimates were developed throughout the basin. These values produce a new estimate of groundwater discharge and nutrient loading to Lake Tahoe. Each of the areas have unique characteristics which warrant regional nutrient loading estimates. These values can then be combined to evaluate the overall estimates of nutrient loading to Lake Tahoe. Table 9-3 summarizes the range and most reasonable estimates of nutrient loading in each area. In addition, the average nutrient concentrations for each region are included in the table.

The loading estimates depicted on a regional basis may be misleading as the Tahoe City/West Shore area contributes significantly higher nitrogen and phosphorus through groundwater annually. This is partly due to the length of shoreline included in this region compared to the rest of the basin. To account for length of shoreline, the loading estimates have been divided by length of shoreline (Table 9-2). This evaluation shows Tahoe Vista/Kings Beach area actually has the highest nitrogen and phosphorus loading per meter of shoreline, 1.6 kg/yr/meter and 0.18 kg/yr/meter, respectively. The total dissolved nitrogen from groundwater per meter of shoreline ranges from 0.01 to 1.6 kg/yr annually. The total dissolved phosphorus from groundwater per meter of shoreline ranges from 0 to 0.18 kg/yr annually.

Table 9-2. Loading Estimates by Length of Shoreline in each Area (kg/yr/meter)

	South Lake Tahoe/Stateline									
Constituent	Emerald Bay to Taylor Creek	Subregion 1	Subregion 2	Subregion 3	Subregion 4	Stateline	Incline Village	Tahoe Vista/ Kings Beach	Tahoe City/ West Shore	East Shore
Total Nitrogen	0.08	0.12	0.39	0.01	0.20	0.27	0.69	1.57	0.96	0.61
Total Phosphorus	0.07	0.01	0.07	0.00	0.04	0.01	0.13	0.18	0.15	0.01

1. All concentrations reported are dissolved.
2. 1 kg/yr = 2.2 lbs/yr

Table 9-3. Range of Groundwater Discharge, Nutrient Loading to Lake Tahoe and Average Nutrient Concentration by Region

Constituent		Region: South Lake Tahoe/Stateline: Emerald Bay to Taylor Creek	Region: South Lake Tahoe/Stateline: Subregion 1	Region: South Lake Tahoe/Stateline: Subregion 2	Region: South Lake Tahoe/Stateline: Subregion 3	Region: South Lake Tahoe/Stateline: Subregion 4	Region: South Lake Tahoe/Stateline: Stateline	Region: Incline Village	Region: Tahoe Vista/ Kings Beach	Region: Tahoe City/ West Shore	Region: East Shore	Total Groundwater Loading to Lake Tahoe
Dissolved Ammonia + Organic (kg/yr)	Minimum	10	110	11	0	86	180	200	1,700	1,400	1,300	
	Maximum	130	710	330	20	460	550	2,100	6,400	17,000	2,300	
	Estimate	70	340	250	9	170	550	1,600	2,700	9,800	2,300	
Average Concentration (mg/L)		0.045	0.71	0.21	0.19	0.23	0.64	0.24	0.27	0.26	0.47	
Dissolved Nitrate (kg/yr)	Minimum	10	12	92	0	15	34	400	1,600	1,300	1,800	
	Maximum	140	64	1,100	68	650	840	11,000	8,600	31,000	3,900	
	Estimate	80	30	530	13	290	95	2,600	6,800	18,000	3,900	
Average Concentration (mg/L)		0.051	0.057	0.44	0.26	0.40	0.11	0.39	0.70	0.47	0.81	
Total Dissolved Nitrogen (kg/yr)	Minimum	20	130	100	1	230	370	60	4,800	2,700	3,100	12,000
	Maximum	270	770	1,300	80	1,300	1,200	13,000	15,000	48,000	6,200	87,000
	Estimate	150	370	780	22	450	650	4,200	9,400	28,000	6,200	50,000
Average Concentration (mg/L)		0.096	0.77	0.65	0.45	0.63	0.75	0.63	0.97	0.73	1.28	
Dissolved Orthophosphate (kg/yr)	Minimum	20	8	4	0	24	7	6	390	1,000	500	
	Maximum	200	43	140	10	72	17	720	1,300	5,400	1,100	
	Estimate	110	15	100	3	60	17	550	820	3,100	900	
Average Concentration (mg/L)		0.071	0.032	0.086	0.062	0.084	0.020	0.082	0.084	0.082	0.019	
Total Dissolved Phosphorus (kg/yr)	Minimum	20	11	7	0	19	11	10	670	1,500	80	2,400
	Maximum	240	59	190	10	100	30	1,000	2,200	7,600	150	12,000
	Estimate	140	28	140	4	83	30	770	1,100	4,400	140	6,800
Average Concentration (mg/L)		0.085	0.055	0.12	0.083	0.12	0.034	0.12	0.11	0.11	0.029	
Methodology		Downgradient	Downgradient	Land Use Weighted	Land Use Weighted	Land Use Weighted	Downgradient	Land Use Weighted	Land Use Weighted	Land Use Weighted	Downgradient	
Discharge Rate (m^3/yr)	Minimum	250,000	230,000	250,000	1,200	370,000	490,000	99,000	6,400,000	14,000,000	2,700,000	
	Maximum	2,800,000	990,000	1,600,000	120,000	860,000	860,000	8,800,000	9,700,000	66,000,000	4,800,000	
	Estimate	1,600,000	470,000	1,200,000	49,000	720,000	860,000	6,700,000	9,700,000	38,000,000	4,800,000	
Percent of Total Groundwater Loading, Total Dissolved Nitrogen		0.30%	0.74%	1.56%	0.04%	0.90%	1.30%	8.40%	18.80%	56.00%	12.40%	
Percent of Total Groundwater Loading, Total Dissolved Phosphorus		2.06%	0.41%	2.06%	0.06%	1.23%	0.44%	11.32%	16.18%	64.71%	2.06%	

9.6 Ambient Nutrient Loading to Lake Tahoe

Ambient nutrient loading represents the nutrient concentrations as of today in undeveloped and undisturbed areas. It is notable that the estimated ambient nutrient loading to Lake Tahoe represents approximately 61% of the phosphorus and 44% of the nitrogen loading. This indicates that anthropogenic sources are more likely to influence the concentration of nitrogen in the subsurface than phosphorus. This result is expected because nitrogen is less likely to adsorb to soil and therefore moves more freely to groundwater. Human activity may also contribute significantly to the phosphorus in the soil, but until the soil becomes saturated with phosphorus, it has a tendency to adsorb to the soil. As the soil in the basin continues to receive phosphorus from human activities, this ambient percentage may decrease.

Table 9-4. Ambient Nutrient Loading to Lake Tahoe by Region

Constituent		Region: South Lake Tahoe/Stateline: Emerald Bay to Taylor Creek	Subregion 1	Subregion 2	Subregion 3	Subregion 4	Stateline	Incline Village	Tahoe Vista/ Kings Beach	Tahoe City/ West Shore	East Shore	Total Groundwater Loading to Lake Tahoe
Ambient Total Dissolved Nitrogen (kg/yr)	Average	150	127	330	13	190	230	1,800	2,600	10,390	1,300	17,000
Ambient Total Dissolved Phosphorus (kg/yr)	Average	80	23	59	2	35	30	330	480	1,890	140	3,100

Notes:

1. All concentrations reported are dissolved.
2. 1 kg/yr = 2.2 lbs/yr

9.7 Comparison to Previous Studies

The estimated total nitrogen and total phosphorus loading to Lake Tahoe from groundwater is 50,000 and 6,800 kg (110,000 and 15,000 lbs) per year, respectively. This is similar to the 60,000 and 4,000 kg (130,000 and 8,800 lbs) developed by Thodal (1997). This constitutes 13% and 15% of the annual nitrogen and phosphorus loading to Lake Tahoe (Table 9-6), which is similar to Thodal's estimates of 15% nitrogen and 10% phosphorus loading annually.

Table 9-5. Current Evaluation Basin Wide Nutrient Loading and Groundwater Discharge Estimates Compared to Historical Estimates.

	Current Evaluation	Thodal 1997	Fogg 2002
Total Dissolved Nitrogen (kg/yr)	50,000	60,000	
Total Dissolved Phosphorus (kg/yr)	6,800	4,000	
Discharge Rate (m^3/yr)	6.4×10^7	4.9×10^7	3.7×10^7

Notes:

1. All concentrations reported are dissolved.
2. 1 m^3/yr = 0.0008 acre-feet/year, 1 kg/yr = 2.2 lbs/yr

The methods used to develop the discharge rate and ultimately the nutrient loading have inherent uncertainty. While there may be a substantial potential for error using the methods herein, the similarity between independent estimates supports the estimates developed. The current evaluation used a combination of Darcy's Law and groundwater modeling to develop the groundwater discharge estimates. The comparison of Darcy's Law calculation to the model results in South Lake Tahoe shows that this is a valid method of estimation. Thodal's study only used Darcy's Law to determine and estimated discharge rate. The nutrient concentrations used in conjunction with the discharge rates were developed regionally in this evaluation while Thodal used a basin-wide average only. Fogg used a completely different method of estimation for groundwater discharge. Fogg developed the groundwater estimate as a residual of the Lake Tahoe Basin water budget. The fact that the estimates are less than two times different is a significant accomplishment in the understanding of groundwater nutrient contribution to Lake Tahoe.

Table 9-6. Percent of Total Nutrient Budget to Lake Tahoe

	Total N, metric tons/yr	Percent of budget	Total P, metric tons/yr	Percent of budget	Soluble P, metric tons/yr	Percent of budget
Atmospheric deposition	234	59%	12.4	28%	5.6	39%
Stream loading	82	21%	13.3	31%	2.4	17%
Direct runoff	23	6%	12.3	28%	2.4	17%
Groundwater	60	15%	4	9%	4	28%
Shoreline erosion	1	0.25%	1.6	4%	-	-
Total	400		43.6		14.4	
Revised Groundwater	50	13%	6.8	15%	6.8	40%
Total	390		46.4		17.2	

Notes: Lake Tahoe Nutrient Budget obtained from Reuter et al. 2002.